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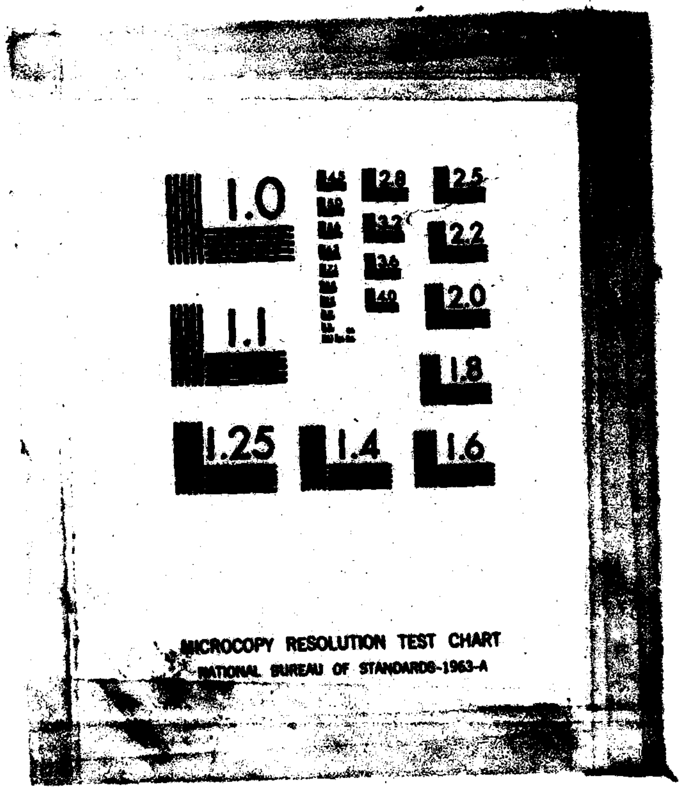
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WALL EFFECTS ON COMBUSTION IN AN ENGINE

Francis E. Fendell, Principal Investigator

Final Report

Contract DAAG29-77-C-0032

15 September 1977 - 14 February 1983

Engineering Sciences Division
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Basic studies of the interaction of a premixed hydrocarbon/air flame with a planar wall have been carried out; these studies were motivated by a reciprocating-piston-engine combustion. The principal experimental methodology was probing of burner-stabilized flames by laser Raman spectroscopy, while the theoretical methodology combined limit-process expansions exploiting large activation energy and numerical integration. The engineering implications of these fundamental studies are now summarized. First, investigations to elucidate the source of unburned hydrocarbon emissions indicated that quenching of a propa-

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) gating flame near a cold (conventional metallic-alloy) wall was primarily owing to thermal effects (as opposed to radical absorption and recombination); however, quench-layer contents persisting near a single cold wall after the combustion event are oxidated before blowdown. The probable sources of exhausted hydrocarbons are two-wall volumes (crevices) and oil layers and carbonaceous deposits (that cyclically absorb, then desorb hydrocarbon vapors). Second, flame propagation is enhanced near hot walls (e.g., near ceramic-capped components); surface-initiated combustion and transient peaks in wall heat transfer could pose possible design problems. Third, alleviation of knock in high-compression-ratio Otto-cycle cylinders by enhanced heat transfer from the end gas by chamber shaping (e.g., increasing surface-to-volume ratio along the flame path) seems practical.

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PREFACE

This project was monitored by James Murray, Robert Singleton, and David Mann of the Engineering Sciences Division of the Army Research Office.

Contributors to the theoretical modeling were W. Bush, G. Carrier, F. Fendell, P. Feldman, and S. Fink. Contributors to the laboratory experiments were H. Bobitch, C. Clendening, R. Hilyard, M. Saffman, and W. Shackleford.

DISCUSSION

Basic experimental and theoretical studies of the interaction of a fuel-lean simple-hydrocarbon/air premixed laminar flame with a planar impervious wall were carried out to elucidate combustion-event phenomena in a reciprocating-piston-type internal-combustion-engine cylinder. Particular attention is paid to the effect of the boundary thermal constraint on flame propagation: whereas flame propagation slows, and the reaction becomes weak and diffused near a conventional metallic-alloy wall (maintained below 525 K for material considerations by air and water cooling), flame propagation may be accelerated owing to reduced heat transfer in the vicinity of a ceramic-capped wall (which may have temperature of 1000 K or more). Of course, the current interest of TARADCOM in innovative low-heat-transfer turbocompounded engines furnishes the primary motivation for the fundamental studies undertaken here.

The theoretical studies combined use of limit-process expansions based on large-Arrhenius-activation energy with numerical integration, while the experimental studies used laser Raman spectroscopy to measure temperature and fuel mole fractions in atmospheric-pressure flames stabilized on heat-sink-type burners. The experiments were limited to the so-called side-wall-type geometry, in which a plate is placed perpendicular to the burner-stabilized flame. Theoretical studies examined not only the side-wall geometry, but also the end-wall geometry (flame isotherms parallel to the wall), and nonisobaric flame propagation in variable-volume enclosures (engine cylinders) as well. Thus, the experimental studies considered only a small subset of the subjects addressed theoretically via Shvab-Zeldovich (engineering-accuracy) formulation.

Since the results either have been reported already in the open technical literature, or are in preparation for such presentation, this final report is limited to very brief sketches of the references listed under publication.

References 1 through 3, 5, and 10 are theoretical examinations of a one-dimensional flame near a solid parallel planar boundary. Two major considerations evolve from solution of the posed parabolic boundary-value problems. First, residual hydrocarbons left near a cold wall owing to the quenching of an approaching flame diffuse toward hot product gas and are quickly oxidated; hence, one-wall quench-layer contents remaining after the combustion event are burned before blowdown, and are not the source of unburned hydrocarbon emissions. Alternative mechanisms (crevice quenching, and cyclic absorption/desorption of hydrocarbon vapor from carbonaceous deposits on the head wall and piston crown and from the oil layer left on the lateral cylinder surface by reciprocating-piston motion) are the source of exhausted unburned hydrocarbons. Second, for hot-enough walls, the acceleration of a propagating flame as it approaches the wall may lead to a sharp peak in heat transfer, or even to surface-initiated flame propagation; hence, large thermal stresses and uncontrolled burning become possible design problems.

References 6 and 13 are theoretical studies, and References 8 and 11 are experimental studies, of a side-wall quench layer. These studies suggest that thermal effects associated with reduction of the Arrhenius factor, rather than absorption and recombination of chain-propagating intermediate species, are the principal mechanism for quenching near cold walls. These studies confirm that hydrocarbons do not persist in the vicinity of cold walls, but diffuse away and are consumed rapidly. In the course of these investigations, it became clear that the purported flat flames stabilized on Botha-Spalding-type burners deviate from one-dimensionality; this departure is owing neither to heat-sink nor burner-edge effects, but rather to expansional slowing (to preserve mass flux) of the stream emerging from the exit face of the porous-sintered-bronze disc. This two-dimensional geometry admits straightforward generalization to a two-wall (or duct-type) crevice geometry, so flame quenching near the piston crown may be examined. Reshaping and reduced heat transfer may abet flame propagation into crevices.

Reference 7 establishes that the observed reduction in hydrocarbon emissions with increase in engine speed, not readily explicable in terms of other mechanisms, is consistent with absorption/desorption from oil layers--

provided these layers are more than 1-2 microns thick and hence not saturated, but rather are subject to control by diffusional processes, as far as hydrocarbon content is concerned.

References 4, 9, and 12 are theoretical studies of nonisobaric flame propagation in a variable-volume enclosure. These studies constitute steps toward evaluating augmented heat transfer from the end gas, as an alternative to (now environmentally constrained) use of metalorganic-salt fuel additives, for avoiding knock in high-compression-ratio, high-thermal-efficiency cylinders. Increasing surface-to-volume ratio during flame transit may counterbalance compressive preheating, such that autoconversion of the final charge in a homogeneous explosion, and consequent pressure-wave effects, are precluded. A suitable three-region generalization of the conventional two-zone treatment of combustion in spark-ignition engines is set forth in Reference 12.

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